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Developing Innovation Systems

Mexico in a Global Context

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University, Knowledge Production and Collaborative Patterns with Industry

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Introduction

This chapter analyses the general characteristics of the scientific base accumulated in institutions of higher education (HEIs) and the way in which research activities developed by these institutions[1] relate to the innovation activities within firms. The aim of the chapter is to identify the forms by which knowledge flows between the two sectors.

There are three arguments which support this chapter: the first relates to the non-linear model of innovation, which is conceived as an interwoven process, possible by virtue of complex interactions between firms and other sectors, such as educational institutions and government agencies (Nelson and Rosenberg, 1993; Gibbons *et al.*, 1994; Etzkowitz and Leydesdorff, 1997; Cimoli and della Giusta, 2000). The second argument relies on the importance of the university scientific base in the innovation process; those institutions, considered to be repositories of basic research, are proving to play a relevant role in that process. However, their participation does not seem to be direct, but adopts an indirect path, making the non-linear model of innovation more plausible.[2] The role of universities in countries such as Mexico is particularly important as in universities are concentrated the greater part of scientific competencies for knowledge production. The third argument refers to two differentiated orientations of university–industry collaboration: one is related to collaborations based on human resource training, mainly professionals, and the other focuses on collaborative activities based on scientific research, in which researchers, professors and postgraduates involved in HEI research activities participate together in attending to specific demands from industries. This chapter focuses on the second orientation.

The study of the relationship between HEI scientific competencies and the manner in which networks of links are set up with firms is carried out on two levels of analysis that are related to the general methodology for the study of the Mexican innovation system:

1. On a macro level of analysis, an assessment is made of the scientific competencies which universities possess as compared to those generated in government institutions and in industry. By the use of different indicators, their

historic development and specific characteristics are identified and compared against international indicators. From this, HEI general scientific and technological capacities can be inferred.

2. On a meso level of analysis, the links between the university scientific base and industry are identified. The aim is to discuss, on the one hand, the magnitude of this phenomenon and, on the other, the dynamics of those interactions. The magnitude is assessed by means of quantitative indicators previously obtained from surveys applied to both HEIs and firms. The dynamics of relationships are analysed by means of qualitative indicators elaborated from different sources. A taxonomy is built on both types of indicators. This chapter highlights the regional outlook and identifies those fields of research in which collaborations are more dynamic, with an attempt to determine whether this aspect relates to the various types of HEIs, their research competencies and the economic characteristics of the regions.

Evolution and current trends of science competencies[3]

In universities in Mexico as well as in other developing countries are concentrated the country's greatest efforts in science, which has for the most part been supported by government budgets. This fact contrasts with the very low participation of industry in research and development (R&D) activities and its financing.

Historically and in very broad terms with regard to the evolution of science and technology (S&T) policies, specific players and institutions have held the role in the promotion of this kind of activity, of which different stages can be identified: (a) in the first stage, the academic elite was the main participant, promoting support for S&T activities during the 1970s, this being continued by the government in the early 1980s; (b) industry and the market emerged as the main players in S&T policies by the end of the 1980s; (c) an interactive, or networking model for policy-making, involving the joint participation of all three sectors, appears to be the feature of the 1990s (Casas and Luna, 1997b). It is worth mentioning that the last type of arrangement is very closely related to a non-linear conception of innovation and, therefore, to a relative increase in collaborations between universities and industry.

During the 1970s, research capacities were concentrated to a large extent in Mexico City (which contributed 75 per cent of the human resources devoted to R&D) and particularly in the National Autonomous University of Mexico (UNAM). At that time, as occurred in other Latin American countries, the role of science and technology was reassessed by government. From 1971 to 1981, the federal expenditure on S&T[4] tripled as a percentage of the gross domestic product (GDP), increasing from 0.15 to 0.46 per cent (Lustig, 1989). Consequently, universities experienced unprecedented growth in enrolment and a significant increase in research capacities due to the allocation of resources to improve infrastructure and the creation of new institutions.[5] On the other hand, the early 1980s were characterized by the dominant authority of the government in an extensive planning project and in the definition of S&T development priorities. During the middle half of this decade, also characterized by a severe economic crisis, GDP fell by 26 per cent and federal expenditure experienced a negative growth (Lustig *et al.*, 1989, p. 19). Research salaries also experienced a considerable drop. Within this context, the National System of Researchers (SNI)[6] was founded in 1984 to reverse the negative trends and the depression of research activities. This stage was characterized by an institutional approach to S&T development, very similar to a linear model of innovation, having as its main goal an increase in the S&T supply. This view was complementary to that of the private sector: within the framework of a closed economy and protectionist policies relative to industry, this sector showed very little interest in the development of scientific activities or in the use of the knowledge produced by universities.

By the end of the 1980s, together with the opening up of the national economy, a market integration model of S&T development emerged as dominant. According to this new economic approach, the production of knowledge should be driven by the demands of industry. Planning was replaced by assessment and particular attention was paid to the quality and pertinence of the production of knowledge. In addition, the intervention of industry in the financing and operation of educational and technological systems was encouraged. Despite the importance of market criteria in the design of policies, the government continued to play a central, albeit different, role in R&D activities. The main purpose of government policies would be to create conditions for the better performance of Mexican industry in a new economic context.

A new stage based on an interactive model oriented towards a trilateral relationship among government, academia and industry is the feature of the 1990s. In theory, this approach would imply an equilibrium between the industrial and institutional parties in the building of networks and partnerships.[7] We document the characteristics of this stage in the following sections.

Stylized facts in scientific capacities in Mexico

When we analyse the distribution of expenditures and personnel devoted to R&D, the distribution of research by fields, the general trends in scientific production, and the distribution of projects by research type, some stylized facts in science capacity can be drawn:

- Whereas government is decreasing its participation in R&D expenditures (from 50 per cent in 1993 to 33 per cent in 1995) and government research institutions are decreasing the concentration of R&D personnel, industry and higher education institutions are increasing theirs. Furthermore, the increase in R&D expenditure of the private sector only occurred between 1993 and 1995 (8 to 21 per cent) (CONACYT, 1996b, 1997c).
- As far as S&T competencies in the 1990s are concerned, it is noticeable that between 1990 and 1996, after ten years of negative growth, there was some recovery in the federal expenditure on S&T, with a growth rate of 6.4 per cent (CONACYT, 1997c).
- When taking into account the distribution of the percentage of expenditures in R&D activities within the HEIs, it is worth pointing out that public HEI still contribute the major proportion, even when private HEIs increased their expend-

iture slightly in these activities in 1995.[8] In private universities, R&D activities are financed by non-governmental resources, and come mainly from donations from the administrative boards and from research contracts with industry and other sources (OECD, 1994).

- With regard to personnel devoted to R&D activities, although separate information is not available for public and private HEIs, it is important to note the total number of SNI members for each of those types of HEIs between 1994 and 1996. From data obtained for 1996 (CONACYT, 1997c), public HEIs concentrate 66 per cent of SNI members, while private universities have 2 per cent. Among public universities, UNAM has 34 per cent of SNI members, public state universities, 16 per cent; the National Polytechnic Institute (IPN), including the Centre for Research and Advanced Studies (CINVESTAV), reached 9 per cent, and the Autonomous Metropolitan University (UAM) 6 per cent. This distribution reflects the fact that resources of excellence in S&T still show a trend towards concentration in few institutions, mainly located in the centre of the country (56 per cent).
- In terms of areas of research, personnel of excellence devoted to R&D activities are mainly found within the biological, biomedical and chemical sciences, and then in physics and mathematics. Personnel in the engineering and technology area, which observed important increases during the period of 1987–91, shows from 1992 a trend to decrease, currently representing 21 per cent of the total members of this system (CONACYT, 1997c).[9]
- Scientific production is difficult to assess adequately, given the severe limitations of information available in the country.[10] The best approach for evaluating scientific production should take into consideration the quantity, quality and relevance of scientific production, by means of a combination of national and world indicators (PETAL, 1990, p. 466). Some quantitative indicators of scientific production with a national approach are already available. The total rate of increase in papers published from 1980 to 1995 has been 97 per cent. It is worth mentioning that significant increases in this rate were observed from 1987 to 1988, (16 per cent) and from 1988 to 1993 (19 per cent) (CONACYT, 1997c).
- In using other complementary sources of information, it is observed that scientific production by fields of research, in the case of UNAM, is concentrated[11] in the biological and health sciences, which report the major amount of publications, a trend that corresponds to the concentration of personnel. Similar trends were obtained from an analysis of publications by SNI researchers in 1991. The greatest productivity was for medicine, biology, physics and chemistry, while lower productivity was observed for certain fields of engineering. This pattern of production by fields of research implicitly refers to both basic and applied sciences, it being difficult to evaluate which predominates.
- The only data available for making international comparisons are those of the Institute for Scientific Information (ISI). According to this source, Mexican scientific production is below the average of the industrialized nations, and also of countries in the Latin American region such as Brazil. The entire body of scientists in Mexico produced in 1995 an average of 2,258 publications, while in industrialized countries the average ranged between 54,536 (Japan) and 257,414 (USA). The disciplines with the greatest number of scientific publications

between 1981 and 1996 were clinical medicine (18 per cent of the total publications), physics (17 per cent) and plant and animal sciences (11 per cent) (CONACYT, 1997d). The greatest Mexican participation in world scientific production is for astrophysics, agriculture and plant and animal sciences (CONACYT, 1997c).

- From citation analysis (CONACYT, 1997d), the major impact factor was for the fields of immunology, molecular biology and neurosciences. Clinical medicine, which stands first in production, occupies the eighth place in impact. This is an example of how citation analysis based on international sources could reflect diverging impacts for fields of national and local interest. Clinical medicine is a field oriented to research on illnesses affecting the Mexican population, and is very probably of low interest for world science.
- Regarding journal impact, the *Revista Mexicana de Astronomía y Astrofísica* and *Salud Mental*[12] have achieved, between 1990 and 1992, an important impact factor when compared internationally (CONACYT, 1997d). Other journals, such as *Revista Archivos de Investigación Médica* and *Revista Mexicana de Física*, are increasing their impact in recent years.
- With citation impact analysis, journal impact analysis and the average of participation of Mexican science in world production (CONACYT, 1997d), it can be argued that Mexican science is important in different fields. The main competencies are found in astrophysics, clinical medicine, molecular biology, neurosciences, agricultural sciences and geosciences. However, it appears to be weak in engineering sciences. The quantitative indicators already available, most limited to ISI coverage, must be complemented with an assessment of the quality and relevance of research activities, with both a national and international perspective.
- With regard to the location of research, a process of institutional and geographic decentralization has been noted. UNAM, in particular, is contributing to a decentralized research policy and reducing its participation in R&D activities, in favour of public state universities, the SEP-CONACYT Centres system[13] and, to a lesser degree, in favour of private universities and public technological institutes. However, scientific competencies are still concentrated in public institutions; thus, between 1991 and 1996 they received 96 per cent of the projects financed by CONACYT and 97 per cent of the funds allocated through research promotion programmes.[14]
- Historically, research has been oriented towards applied and experimental rather than basic science. Currently, however, the distribution of expenditures among these three types of research is very similar (CONACYT, 1997d). With respect to research fields, it can be observed that PACIME[15] has favoured basic sciences over applied sciences (which include biology and engineering) and other sciences related to the social concerns of the country, such as health and natural resources. Even if the data are weak for defining the specialization patterns in science by fields of knowledge, it is useful to argue that Mexican research seems to be stronger in biomedical (including biotechnology), clinical medicine, physics and earth sciences, with both a basic and applied approach, than engineering and technology.

The magnitude of university–industry collaboration: some indicators

Historically university–industry relationships have been weak in Mexico. However, beginning in the 1990s, there has been more interest from HEIs in increasing their collaboration with industry. Various factors have contributed to the growth in relationships between university and industry, at both national and international levels,[16] the most important being the North American Free Trade Agreement (NAFTA), the guiding principle behind the educational modernization programme in the late 1980s and the intervention of the private sector in the financing and functioning of the educational and technological systems.

Such factors have led to the introduction, from the late 1980s, of different policies and mechanisms by government, firms and HEIs in order to promote more frequent collaborations (Casas and Luna, 1997a and b). On behalf of government, mechanisms to increase private sector participation in education and professional training directed to the needs of Mexican society were applied. In terms of HEIs, mechanisms such as professional practices, school–industry programmes, external advisory councils with the participation of the private sector, alumni associations and centres for technological administration are some of the outstanding measures introduced. And finally, as to firms, some large enterprises have signed formal contracts with HEIs, and some important entrepreneurial associations have explicitly expressed their desire to cooperate with the government and the educational sector for the definition of industrial and technological policies.

Two different orientations should be distinguished when referring to university–industry relationships (Casas and Luna, 1997a and b).[17] The first involves collaborations based on the training of professionals and business advisors oriented towards satisfying the organizational and technical demands of industry. This orientation has been adopted mainly by private universities, which were created to address the demands of industry. In view of the new economic model currently applied in Mexico, this trend has been intensified by most public higher education institutions, which are introducing mechanisms and programmes to make human resource training adequate for the demands of industry.

The second orientation refers to collaborations that are established on the basis of research competencies and are conducted for the development of products and processes, their improvement or specialized technological services addressing the interests of industries. This is a new trend that can be found in the larger public institutions of higher education, which concentrate research and personnel resources in S&T and are at present developing mechanisms to established formal agreements, mainly with large firms. Some private universities that during the past decade have built capacities in research activities are also involved in developing research projects of interest for industry.

One of the main differences with regard to this second trend is the role played by public and private universities. Public universities develop research oriented towards basic science and this is supported mainly by their own university budget. Private universities are oriented mainly towards diagnosis and consultancy activities utilizing resources from industry and governmental programmes and to a lesser degree by their own budget.

In order to have a rough idea of the magnitude of university–industry relations, we utilize here quantitative indicators from several surveys applied to both HEIs[18] and industries.[19] It should be clarified that these surveys deal with both orientations of collaboration referred to previously. These surveys are relevant to document the following: the organizational structures, the financial resources, the quantity of projects, and the intensity of the use of the university knowledge base.

Organizational structures

One indicator of the recent changes regarding relationships with industry is that more than half of the institutions surveyed have introduced organizational structures to administrate and promote those interactions. They respond to different approaches to collaboration. In large universities, mainly public such as UNAM, IPN and the University of Guadalajara, specific centres exist for link-up activities; in other institutions, such as technological institutes, specific departments are in charge of linkage and technological administration. Private universities have also created specific units to integrate their activities with industry, an example being the structure of the Monterrey Technological Institute (ITESM-Monterrey Campus), where each department develops its own strategy.

In some cases, these activities are integrated into extension departments; in others, they are part of the offices for academic exchange or are incorporated into postgraduate departments. The majority of link-up activities based on research are coordinated directly by faculties or by postgraduate and research divisions, although they exist as specific link-up units within the institution. The existence of these types of units does not involve, in the majority of cases, a centralization or concentration of decisions for collaboration. Rather, in some cases, linkage units operate on a decentralized model in which each research centre seeks better mechanisms for interrelating with industry, depending on its fields of research, and on its technical and experience capabilities. It would seem, according to Gould (1997), that a mixture of centralized and decentralized structures offers the most advantages.

Financial resources

With regard to financial resources in public as well as in private HEIs, the greatest support for collaboration comes from their own budgets, while companies provide a very reduced amount of funding. Despite the existence of government programmes for link-up activities, these support the HEIs in a very limited manner.[20] The resources obtained from the collaboration with industry, although they continue to be very low in comparison to the HEIs' total budget, have increased over the past few years.[21] In addition to the financing obtained from industry, HEIs also sought out other external financial sources to support their research activities. All these sources have allowed some HEIs to increase their research competencies by means of laboratories and equipment and to be in a better position to attend to demands from the industrial sector.

Quantity of projects

Scarce information has been gathered in Mexico, similar to other OECD countries, that could be useful to evaluate the quantity of university–industry projects. A broad assessment of the quantity of these relationships is that during the past decade joint projects have been scarce and university–industry collaborations were weak. However, according to the ANUIES Survey (1997), between 1994 and 1996 HEIs increased their collaboration projects, oriented to both human resource training and research activities, on an average of 89 per cent. The highest rates were for private universities (238 per cent), followed by public technological institutes (93 per cent), while public universities increased projects by 41 per cent. This information reveals that during the period of 1994–6, HEIs have intensified their relationships with industry, very probably as an effect of policies and mechanisms already introduced.

However, if we consider the number of projects supported on research activities separately, the trend is quite different. From a survey applied in 1997 to 1,322 firms in the manufacturing sector (CONACYT, 1997a), 63 per cent were developing innovative activities. The results reported that only 4 per cent of these firms had established collaborative agreements with universities for the improvement of products and processes; most were Mexican firms. Of those enterprises, 42 per cent reported that agreements with universities were significant, while for 35 per cent, the relationships were moderately significant and, for the rest, were of minor importance.

Data obtained from the two previously mentioned surveys indicate two important points: first, the relative weight that each of the actors gives to collaborative activities, and the fact that innovative firms do not seem to be interested in knowledge produced in HEIs; second, HEIs establish relations with a wider spectrum of industries and not specifically with those characterized as innovative ones. This trend is also explained by the broad group of objectives of collaborations, among which services stand out.

From the previous discussion it seems that HEI had little participation in the development or improvement of technological process and products by industries. In fact, some recent studies (Casas and Luna, 1997a and b) have documented that many projects are based on informal interactions, and are established with small and medium firms, which are not characterized by innovative activities but by the assistance of the HEIs to solve specific organizational or technical problems. Other studies carried out within the framework of the OECD (Laursen and Lindgaard, 1996; Vithlani, 1996) in Europe and the USA have also shown that collaborations between these two sectors have limited direct impact on the innovative performance of firms and result in few exploitable product or process developments (OECD, 1996a, p. 3). We can highlight here that the indirect impact of universities in the innovation process is a feature of both developed and developing countries.

Intensity of the use of university knowledge by firms

Collaborative projects generally involve a variety of activities, among which research and technological development are at a medium level of intensity. As far as research is concerned, there is a variety of linkage activities, such as basic research, joint research, technological development, technology transfer, technology licensing and technical assistance. However, most of the activities in this category are related to technical assistance, engineering and information services, these demands from industry being conditioned by the existence in HEIs of facilities, including laboratories and equipment.

The existence of infrastructure (laboratories and equipment) is a precondition for HEIs to be able to respond to industry demands (ANUIES, 1997). But the accumulation of knowledge at the academic level, expressed in tacit knowledge embodied in the scientific personnel, is also a precondition for collaboration, as other studies have documented (OECD, 1996a; Vithlani, 1996). Some private institutions have made great efforts to contract PhD academics and to obtain sophisticated equipment in order to interact with industry through specialized services, such as in the case of ITESM.[22] On the other hand, public institutions such as UNAM and IPN satisfy the need for specific technical services to industry, given the infrastructure capabilities they have accumulated.[23]

In view of the characteristics of the accumulation of research in HEIs, these constitute a source of information for industry and an opportunity to observe the progress being made in certain technological fields. In some specific cases (ANUIES, 1996; CONACYT, 1997; Casas and Luna, 1997a and b), it has been shown that there is a demand for tacit knowledge on the part of firms, through the mobility of personnel and the use of publications and patents produced by the universities, which represent codified knowledge.

However, the degree of intensity in the utilization of this knowledge continues to be low for specific industrial sectors. In the case of the automotive industry (see Chapter 15), only 2 per cent of firms hire R&D services from public universities and 0.7 per cent hire from public and private technology centres. As for the pharmaceutical industry, links with universities and public research organizations are short term, specific and informal, and are generally reserved for such activities as clinical tests but not for basic research (see Chapter 12). Regarding the chemical industry (see Chapter 11), it has been argued that 'very few chemical companies have approached universities or research centres for technological developments', but Arvanitis and Villvicencio additionally argue that the weakness of the relationships with universities is a wider problem in dealing with the difficulty that companies have in establishing linkages with any type of suppliers or technical associates.

Despite the low intensity of the use of university knowledge by firms in quantitative terms, some important foreign firms established in Mexico, such as Procter & Gamble, Ciba-Geigy AG, AT&T Corp., Hoechst AKT, Bayer AKT, the BASF Group, Rhom and Haas Company, and Motorola, Inc, have developed formal collaboration agreements with certain large universities (UNAM, UAM and, to a lesser degree, the Autonomous University of Nuevo León and, among the private universities, the ITESM and the Universidad de la Laguna) (IIS-UNAM, 1985). These agreements, of very different natures and with a variety of objectives, have lasted for several years and have been very useful as a knowledge flow mechanism, facilitating personnel mobility and the transmission of tacit knowledge. This fact proves to be important as such firms, included among the main ones taking out patents in this country (CONACYT, 1997a, 1997b), are recognizing the importance of those HEIs that concentrate research capacities in Mexico.

The dynamics of university–industry collaboration

The study of the dynamics of collaboration between universities and industry enables us to appreciate that such relationships are possible through complex interactions that may be considered inherent to the interactive or non-linear model of scientific-technical knowledge production.

From data obtained from several programmes that have supported collaboration in various different regional environments[24] and the use of other sources of information,[25] it was possible to gather a group of qualitative indicators of the current dynamics of collaborations based on research activities.[26]

The regional dimension

University–industry collaborations in Mexico are taking place on a regional basis, given the geographic proximity between research institutions and specific problems related to local natural resources and industrial activities. Some regions stand out (the Centre, the Northeast, the West and the Bajío region) for their greater dynamism regarding linkage; other regions may be considered as intermediate (the North-Central states of the country), whereas some others are characterized by their lower level of linkage (mainly the states in the South and Gulf regions and the Northwest).

Although it is possible to identify a certain profile or regional specialization from the frequency of the links made between specific areas of knowledge and economic sectors, undoubted are the great diversity that exists regarding the type of academic institutions involved, the type of fields of knowledge, the profile of demand or type of firm, the objectives of the collaboration and its geographic scale, and the technological sectors involved.

The complementary nature of formal and informal relations

With regard to the type of relationships which are established, although formal relationships have acquired importance during the past few years, informal interactions continue to carry considerable weight. The majority of the sources consulted report only the collaborations already established on a written agreement or contract. However, informal relationships carry a significant weight in the process culminating in the setting up of a formal agreement; they are also relevant in the links between academic institutions and innovative firms that have developed new products and processes.[27] Other studies have documented that 'the effects of networking and gate-keeping, via informal contacts, can be substantial' (OECD, 1996a).

The diversity of initiatives

Relationships between academy and industry based on research activities do not appear to follow a pattern regarding the origin of the initiative, which may come from different actors. Among the most common, the following initiative origins were identified: (a) large national or foreign companies; (b) business associations or local agricultural organizations, particularly where small and medium-sized firms use traditional technologies; (c) micro and small innovative firms; and (d) researchers or groups of researchers in universities and from academic institutions in general.

Links are generally of a spontaneous nature, stemming from bonds of trust and personal relationships. However, the consolidation of collaborative relationships frequently depends on the support provided by governmental programmes and on the facilities offered by the academic institutions in terms of economic, institutional and legal resources. In the process of setting up collaborative bonds there is, consequently, a dynamic relationship between supply and demand.

In the case of UNAM, we found examples which document both directions of the initiative. In considering the data from 1995 and 1996 jointly, the distribution of initiatives for linkage registered the following behaviour: in 1995, of 80 agreements for collaboration handled by the Centre for Technological Innovation (CIT), of the aforementioned university, 23 per cent responded to the demand from industry, while in 1996, of the 87 agreements, 43 per cent came from the firm's initiative (CIT-UNAM, 1997).

The variety of objectives

With regard to relationships based on research, the objectives are diverse. In the most dynamic regions, collaborations concerned with the development or improvement of products and processes are predominant (32 per cent), followed by scientific and/or technological research (24 per cent), administrative diagnoses on production (19 per cent), and optimization of production (12 per cent). However, the objectives of collaboration are usually multiple and occur simultaneously or successively. They include the training of firm personnel by the universities or of students at firms, human resource formation at the undergraduate and postgraduate levels, and technological services that could be routine or could require highly specialized knowledge.

An example is the Instituto Tecnológico de Celaya, which bases a large portion of its relationships with regional firms on interactions generated through the formation of human resources at both the undergraduate and postgraduate levels. However, these relationships have generated new objectives, such as specialized services, consultancy, the improvement of technology and some research projects for firms.

The interdisciplinarity of knowledge flows

The attempts to generate links with industry produce various types of transfer of knowledge. These range from the traditional knowledge inherent to a particular discipline to that produced in an interdisciplinary mode. In the current globalization environment, this implies cross-border knowledge, more characteristic of the new technologies. On reviewing the agreements set up through the CIT-UNAM, we note that these have involved both relationships in traditional scientific fields (mechanical engineering and chemistry, agronomy, veterinary) and participation in fields characterized by new technologies (biotechnology and material sciences).

The complexity of regional configurations

While analysing the characteristics of collaborations in various regions of the country, it was possible to discover that their construction is extremely complex. Although geographic proximity plays an important role, we frequently find links which go beyond, crossing state, regional and national boundaries to encompass economic sectors. This is the case for the mining sector cluster in the Northwest of the country which, although its original nucleus is at the State University of San Luis Potosí and the mining industry in that state, it is expanding towards other states in the region that have mineral resources. It involves other mining companies and HEIs, such as the Instituto Tecnológico de Saltillo and CINVESTAV, both located in Coahuila. This cluster crosses Mexican borders, establishing collaborations between Mexican institutions doing research in mining with institutions in Canada.

The building of networks between various participants

If the academic institutions are taken as a unit, collaboration with other entities carrying out national and international research is extremely frequent. But even if the firm is taken as a unit, one sees that collaboration based on research sometimes involves links that combine relationships, among which the following stand out: (a) firms that establish relationships with different types of public academic institutions; (b) firms that collaborate with public and private universities (particularly at the state level); (c) firms that interrelate with various kinds of institutions, such as public and private universities, Mexican or foreign academic institutions or research centres.

An example of the first type of collaboration is the scientific exchange network in agriculture in the Bajío region. It allows the flow of knowledge on agricultural problems between different types of institutions that carry out research in this field[28] and maintain a close interaction with different associations of local agricultural associations and cattle farmers in the region. Furthermore, with the initiative of the CINVESTAV-Irapuato, and given the demand for research on the part of producers, a postgraduate programme was created aimed at strengthening the research into food and biotechnology within the region (Paredes López *et al.*, 1996).

With regard to the second and third types, relevant exchanges are observed in the Northeast region between the ITESM, Monterrey Campus and the Universidad Autónoma de Nuevo León. The latter also interacts with a group of large national and foreign companies established in the state of Nuevo León.

It is worth mentioning that despite the significant weight of individual firms, the participation of business associations and local producer associations stands out in fostering collaborative activities with universities.

The diversity of sectors

There is no pattern at the national level regarding the collaboration of universities and industry by type of firm, differentiated by size or by the sector to which they belong. The relationships between fields of knowledge and industrial branches are extremely irregular, particularly where areas of knowledge are connected to high technology fields. Additionally, there is no correlation between industrial sectors of high technology and innovation, because the development of products and processes is found in both traditional and novel technology sectors.

To illustrate the dynamic described above, the case of the University of Guadalajara, is noteworthy; its Department of Wood, Cellulose and Paper has formalized research projects with firms belonging to different industrial sectors. In this way, it simultaneously collaborates with paper-producing firms, with associations of furniture manufacturers and with associations of tequila producers.

Problems for knowledge flow

The main problems for the flow of knowledge range from the lack of an innovative culture on behalf of firms,[29] to the incipient institutional strategies for linkage activities in HEIs, to the inadequately defined technological and industrial policies of the government. In general, obstacles for university–industry relations are part of a broad complex of factors inherent to universities, industries and government.

Among the most important are the following: (a) a lack of coordination among the three participants; (b) limited financial resources and capital to sustain technological collaboration; (c) the dilemma between economic competitiveness criteria and adequate evaluation of scientific and technological activities; (d) the weakness of appropriate mechanisms for the flow of knowledge, particularly expressed in intermediate or interface structures; (e) the lack of definition of a legal framework to sustain collaboration; (f) the inherent conflict between public and private knowledge, and the consequent dilemma for academia between the unrestricted freedom of research and the secrecy demanded from industry; (g) the inadequate and almost non-existent policies and incentives for collaborative arrangements for innovation; and (h) the low value of scientific knowledge as conceived by entrepreneurs.

One problem that deserves attention is the legal framework. Definitions such as the pertinence or non-pertinence for patenting in HEIs and the way in which firms need to protect their innovations (patents or industrial secrets) affect knowledge networks. Secrecy is a problem for both universities and industries, for the former because they have to protect their research developments, and for the latter because the definition of demands or the flow of personnel affects the confidentiality of industrial technological strategies, an issue which limits collaboration with universities.

Taxonomy of university–industry collaboration

From previous quantitative and qualitative indicators, specific trends have been identified, from which we have built a taxonomy (see Table 9.1). The main characteristics that reflect the current status of university and industry collaborations are the following.

1. Science-based university industry collaborations are found mainly in those public national universities which concentrate major efforts in research, even when the quantity of relationships is still limited.

2. The existence of scientific competencies, in terms of both personnel and infrastructure in HEIs, provides a type of comparative advantage to universities with a science base. However, these capacities *per se* are not the only factor needed to establish collaborative activities. Governmental programmes and a culture of innovation in firms are necessary to complement that condition.
3. The initiative to establish collaborations comes principally from HEIs, i.e. from the supply side. Some institutions have created mechanisms and programmes to orient their research activities towards industry, while others do not have institutional support and rely on the negotiation of contracts with industry on the researchers themselves.
4. The objectives of collaboration are multiple and are scarcely oriented to innovation or technological development. Despite the existence of the two orientations of collaboration between university and industry, the empirical evidence reflects their interrelation; in other words, human resource training and other collaborative objectives based on research are frequently interwoven.
5. Knowledge mainly flows through mobility of graduate students and researchers. This is a pattern followed by both private and public universities. In fact, graduate student mobility is at present the most efficient way to begin to build knowledge networks to respond to the demands of the productive sectors. In view of this, the dominant trend of knowledge flow between universities and industries in Mexico is accomplished through tacit forms.
6. Collaborative activities between universities and firms are based on formal, spontaneous and sporadic relationships, and even if the ingredient of informal relationships remains strong and contributes to the consolidation of collaboration, the dominant trend is to formalize them through agreements and contracts for specific purposes. However, these relationships tend to be spontaneous and do not constitute a part of institutional policies induced by HEI policies, or by industrial or government strategies.
7. Funding for linkage activities derives mainly from university budgets. The level of funding from industry is particularly low for public HEIs. This is a problem that deserves attention, as some universities assume expenses that correspond to firms. Public HEIs have not yet developed an entrepreneurial culture and do not have a clear definition regarding the cost of knowledge. This is the case for public technological institutes and other public universities that devote part of their postgraduate teaching efforts or the use of the infrastructure and research time to respond to the demands, which only contribute a low percentage of the real cost of collaboration.
8. From previous observations, it is worth highlighting that the dominant problem regarding university–industry collaboration is the lack of coordination among the participants. However, the lack of a governmental technology and an innovation policy also prevents a major impact of university–industry collaborations that could favour and support regional development. This would allow the establishment of networks among research institutions, a recombination of science competencies and improved collaboration with industry and other economic sectors.

Table 9.1 Taxonomy of Science-based University–Industry Collaborations

Main characteristics	Current forms	Dominant trends
Types of HEIs, with a science base, collaborating with industry	• Public national universities • State public universities • Private universities • Technological institutes	• Public national universities
Origin of the initiative of collaboration	• Higher education institutions • Industry • Government	• Higher education institutions
Determinant factors for collaborations	• Scientific competencies in HEIs • Infrastructure in HEIs • Industrial capabilities • Government policies	• Scientific competencies and infrastructure in HEIs
Objectives of collaborations	• Innovation • Technology development • Product, process or production improvement • Specialized technical services • Routine services • Research activities • Graduate students for industry • Technical personnel training	• Technical personnel training • Product, process and production improvement • Routine services • Specialized technical services • Graduate students for industry • Research activities
Types of knowledge flows	• Codified (publications and patents) • Tacit (personnel mobility)	• Tacit knowledge (graduate student mobility)
Kind of relationships	• Informal/formal • Spontaneous/induced[a] • Sporadic/lasting	• Formal, spontaneous and sporadic
Main funding sources	• Government • Industry • HEIs	• HEIs
Obstacles	• Lack of coordination • Lack of financial resources • Market criteria v. collaboration • Public v. privatization of knowledge • Administrative slowness • Lack of policies and incentives • Under-valorization of scientific knowledge • Lack of interfaces and legal framework • Secrecy v. research freedom	• Lack of coordination • Lack of policies and incentives • Conflicts between public and private knowledge • Tensions between research freedom and secrecy

This taxonomy is based on the systematization of the main characteristics found in the analysis of the magnitude and the dynamics of collaborations.

[a] This characteristic refers to the existence or non-existence of institutional policies for linking activities.

Conclusions

In general terms, it can be stated that Mexico is considerably behind with regard to the production of knowledge on a global scale. When compared to other countries, such as the USA, Japan and the UK, Mexico shows a pattern of generation of knowledge in which government encouragement is weak,[30] there is no determined support from the business sector and the HEIs participate in R&D activities with the largest share.

Despite these general trends, over the past three decades the country has increased its incorporation into the world of science, developing its competencies largely in the HEI sector. The emphasis on basic and applied science has led some HEIs and knowledge sectors – biotechnology, astronomy, biomedicine, among others – to the forefront of knowledge. However, engineering and technology, even if they are being importantly developed in HEIs, are less supported by financing governmental programmes and by current evaluation criteria.

This chapter has demonstrated that science-based university–industry collaborations are still very weak. Despite this, information gathered by this study shows an emergent increasing trend towards collaboration and a rich horizon of possibilities for interactions between university and industry. The analysis has led us to recognize that these interactions are oriented to a variety of purposes and are not centred on the development of technology. Among different purposes stand out relationships oriented to the training of human resources, and collaborative activities based on scientific research, which take place simultaneously or consequently. This suggests that Mexican universities could be playing an indirect role in the innovation process, given that the transfer of tacit knowledge is currently the main means for collaborations.

The study of the dynamics between university and industry made it possible to appreciate that relationships are based on very complex interactions, which are providing a learning process and multiple forms of networking among the actors. This feature permits us to argue that an interactive non-linear model is beginning to be applied for the development of knowledge.

The decentralization process of research activities is creating the conditions for networking at the regional level. In fact, this study documented that important collaborations take place on a regional basis, given the geographic proximity between research organizations and the consideration of specific problems related to local natural resources and industrial activities. However, these efforts should be strengthened by regional policies to impact regional social and economic development.

From the above discussion, we can argue that university–industry collaborations constitute an innovative factor for firms, as much as their relationships with suppliers, customers or their own R&D capabilities. However, given that in Mexico research competencies are largely to be found in the HEIs, this factor should be of greater importance for firms. From the analysis carried out to this point, it is clear that the transfer of knowledge from academy to industry, to a greater extent, occurs spontaneously, and that increasing and consolidating that collaboration requires programmes and incentives from both universities and firms to foster it.

Quantitative and qualitative indicators were useful to build a taxonomy that identified the dominant trends in the collaboration between university and industry based on research activities. This taxonomy highlighted, among other elements, the leading role of universities in knowledge networking and the conflicts of interest derived from the privatization of public knowledge and the tension between research freedom and oriented research. These issues deserve serious consideration by university, government and industrial spheres.

In general, the most pressing concern regarding university–industry collaboration is the dispersion of efforts, the lack of equilibrium between the supply and demand of knowledge and the lack of the use of knowledge generated in HEIs by the production system. As was stressed in Part 1, the Mexican production system has developed an industrial structure characterized by low technological opportunities, low demand of knowledge produced locally and high interaction with firms and institutions localized abroad. This set of paths indicates a critical coordination problem that undoubtedly affects the configuration of the national innovation system.

Notes

1. In Mexico HEIs are a heterogeneous group of institutions with very different objectives and functions. Within this structure different sub-systems are distinguished: public universities (autonomous, national or state and technological) that mainly receive financial support from federal and state governments to pursue both teaching and research activities, and technological institutes, widespread throughout the country, with postgraduate programmes and research activities, that are supported by the Ministry of Public Education; and private universities that channel their own budgets for postgraduate programmes and research activities.
2. Different papers have documented the importance of knowledge produced in universities and the developing role these institutions are playing as R&D providers for the innovative process. Among others, the following are worth mentioning: Rosenberg and Nelson (1994), OECD (1996a, 1997b, d), Mansfield (1991), Etzkowitz and Leydesdorff (1997), Nelson (1993), Edquist and Lundvall (1993) and Johnson and Lundvall (1994).
3. The analysis in this section is supported mainly by three data sources: CONACYT (1976), various issues published in 1997 and Lustig *et al.* (1989). It is worth mentioning that Mexico does not have historically accurate series on the evolution of R&D activities from the 1970s to the 1990s. This is mainly due to the diverse definitions and the different components used to characterize S&T and R&D activities in different periods. For this reason, data only indicate general trends. During the 1970s, statistics referring to R&D included basic research, research oriented to sectors of application and research oriented to general knowledge of national reality (CONACYT, 1976), while during the 1990s, R&D includes basic, applied and experimental development, and is one of the components of S&T activities that integrate, in addition to R&D, scientific and technical education and scientific and technological services (CONACYT, 1997c, and other issues).
4. It is worth noting that S&T expenditure includes scientific and technical education and services (CONACYT, 1997c).
5. Among these were the Autonomous Metropolitan University (UAM) and the Centre for Advanced Research and Studies (CINVESTAV), an excellence centre that is part of the National Polytechnic Institute (IPN), which in the future would play a relevant role in the development of S&T in Mexico.
6. The National System of Researchers is a programme of incentives geared to recognize the work of the most productive and qualified researchers, by means of peer evaluation, resulting

in the assignment of a scholarship, for three-year periods, to compensate for the low salaries in universities.

7. Although this model has not been established, in the 1990s several trends were slightly but significantly reversed with regard to the amount and location of R&D activities in comparison to the trends observed during the 1970s.

8. Data for public and private HEIs in 1995 were elaborated by the authors from information included in CONACYT (1997d).

9. This was owing mainly to inadequate recognition of technological and engineering activities within the criteria of evaluation applied by SNI, which tended to favour scientific criteria rather than to include an adequate evaluation of activities developed by engineers whose products do not correspond to scientific activities.

10. The only sources available are the number of papers published in journals included in the *Science Citation Index* of the Institute for Scientific Information and other analyses of a bibliometric nature developed from that source, which in general present strong limitations for countries such as Mexico. Critical analysis of the use of these sources can be consulted in Velho (1985).

11. This level of aggregation of scientific areas offered by CONACYT has not succeeded in elaborating a comprehensive classification of scientific fields, and within the different programmes, leans towards science and technology, in which various classifications are used. This is a problem that should be addressed by policy-makers in order to achieve a more accurate information base on science and technology competencies that would support rational policies.

12. This journal from 1992 has the name of *Archives of Medical Research* and from January 1999 is edited in Mexico but published by Elsevier, New York. Its impact factor has raised from 0.392 in 1997 to 0.632 in 1998.

13. See Chapter 7 of this book, where these centres are analysed.

14. Through these programmes, CONACYT channels funds additional to those from research institutions. Their operation involves researchers competing to obtain funding and assessment of their proposals in terms of quality and the academic progress of the researchers involved.

15. The only available source for analysing research fields is the Program to Support Science (PACIME), operated by CONACYT from 1991/1996. This weakness has already been highlighted by OECD (1994), when analysing the distribution of funding by area of research.

16. A detailed analysis of these factors may be consulted in Casas and Luna (1997). In particular, the general introduction to the book and Chapters 3, 4 and 5 should be consulted.

17. It is very difficult to separate purely the linkage activities related to human resource training from those related to research activities, because they are often pursued simultaneously. Given this fact, reference is made in this section to collaborative activities based on research which frequently implies human resource training at postgraduate levels.

18. Information from the following surveys is used: *Encuesta sobre Vinculación Academia-Empresa*, CONACYT and ANUIES, 1996; *Oferta Institucional de Servicios Externos y Desarrollos Tecnológicos*, IPN, April 1996, and *Oferta de Servicios Tecnológicos de las IES y Centros de Investigación Tecnologica del país*, IPN, November 1996.

19. Information from the following surveys is used: ENESTYC, *Encuesta Nacional de Empleo, Salarios*, INEGI, 1995; *Encuesta Nacional de Innovación*, CONACYT, 1997, and *Encuesta sobre la problemática de la empresa mexicana ante el reto de la modernización, FASE II*, July 1994, Nacional Financiera, Mexico.

20. An example is the CONACYT Academy–Industry Linkage, which allocates resources for collaboration projects between HEI and industry. This programme supported, between 1992

and 1995, 95 projects, with an investment of 21,911,735 Mexican pesos, while from 1995 to 1997 it supported only seven projects with an investment of 1,310,733 Mexican pesos.

21. A recent survey (IPN, 1996a, 1996b) found that 44 per cent of the institutions surveyed obtain approximately 10 per cent of their overall budget from collaborative activities, and only 25 per cent of the institutions reported obtaining 50 per cent of their budget from those activities.

22. This is the case of the Instituto Tecnológico de Monterrey (Campus Monterrey), which has created the Centre for Environmental Quality, and established an infrastructure to offer analytical services to industry in the fields of air and water quality, dangerous waste products and sewage.

23. A very important case is the Faculty of Chemistry at UNAM, which develops specialized analyses for the pharmaceutical and food as well as to other branches of industry (Casas and De Gortari, 1997, p. 191).

24. Among others the Academy–Industry Link Programme and Regional Research Systems, are both operated by CONACYT. The aim of the former, begun in 1992, has been partially to support research projects for which there is private sector support. In general, projects are proposed by HEIs, which interest a potential user. The second most recently created programme operates on the basis of priority areas identified by forums where representatives of academy, industry and state governments participate and where relevant themes are defined for different regions of the country. After identification of the relevant areas, an invitation is issued for the submission of research projects, which must have the guarantee and financing of a potential user.

25. For this purpose, the information used was gathered for the study 'Successful Cases of Innovative Companies', Deputy Director of Scientific and Technological Policy, CONACYT and information presented in the study of Corona (1997). Also used was information collected for the ANUIES/ALO study, *Catálogo de Casos. Vinculación entre los Sectores Académico y Productivo en México y EU*, Mexico, 1996.

26. Very little information was found with regard to the dynamics of knowledge flows (mobility of personnel, co-publications, co-patenting, etc.). A study should be requisitioned for that purpose, which exceeds the remit of this chapter.

27. From a study of these (Corona, 1997) and considering exclusively the firms linked with the HEIs, it is seen that of a total 74 firms, 35.1 per cent, have informal relations with the HEIs and that a majority are lasting relationships, which represent 28.2 per cent.

28. As is the case with the Autonomous University of Querétaro (UAQ), the Autonomous University of Aguascalientes (UAGS), the University of Guanajuato (UGTO) and the Centre for Research and Advanced Studies in Irapuato (CINVESTAV).

29. Other chapters included in this volume document this situation.

30. Mexico currently dedicates 0.33 per cent of the GDP to expenditure to R&D, while other countries of average development, such as Spain, dedicate 0.80 per cent and industrialized countries, between 1.61 and 3 per cent (OECD 1997e).